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CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF HARVARD UNIVERSITY.

INFLUENCE OF MAGNETISM UPON THERMAL CONDUCTIVITY.

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THE following experiments were made in order to test Maggi's results * in regard to the effect of magnetism upon the thermal conductivity of iron. Maggi's conclusions have never been confirmed, and have been much doubted by other observers. The experiments of Sir W. Thomson,† in which he found that longitudinal magnetization diminished, while transverse magnetization increased the electrical conductivity of iron, afford — from the fact that electrical and thermal conductivities are in general proportional — the chief confirmation of Maggi's results. The experiments of Thomson have, however, been questioned.

In the method employed by Maggi, a circular plate of soft iron was placed horizontally upon the poles of a vertical horseshoe magnet. Through the centre of the plate passed a lead tube conveying steam. The surface of the plate was covered with a mixture of oil and wax. When the magnet was made, the melted wax was bounded by an ellipse. If the conductivity had been equal in all directions, it would have been bounded by a circle. The long axis of the ellipse was perpendicular to the line joining the two poles; the short axis was parallel to the line. The ratio of the axes was 6 : 5. The two poles were separated from the iron plate by paper. In order to compensate for the direct effect of the poles upon the flow of heat, two bars of soft iron were placed symmetrically beneath the plate, at the extremities of the diameter, perpendicular to the line joining the poles. No effort seems to have been made to avoid the effect due

* Bibl. Univ. Archiv., 1850.

† Phil. Trans., vol. cxlvi.

to the frictional generation of heat in the magnetic coil. Several other complicating causes are apparent in the arrangement which Maggi used.

A year ago we made some experiments, by a rather rough method, to find the effect of magnetism upon thermal conductivity, and obtained decidedly negative results. The same results have been obtained in the present experiments, though a much more sensitive arrangement was employed. The following method was used. A bar of soft Norway iron, 95 cm. long, 1.3 cm. wide, and 0.2 cm. in thickness, was placed horizontally through the sides of a wooden box 6 cm. wide, and 25 cm. high. The top and one side of the box were removed. 17 cm. from each end of the bar was soldered a thick German silver wire. Each projecting arm of the bar was enclosed in a glass tube 1.4 cm. in diameter. The ends of the tubes were closed with cotton. The ends of the iron bar projected slightly beyond the ends of the tubes, and were exposed to the air of the room. One arm of the bar was placed between the poles of a large electro-magnet, with its flat surface perpendicular to the axis of the magnet. The axes of the poles were in the same horizontal line, perpendicular to the bar. The tube between the magnetic poles was wrapped in a piece of thick asbestos cloth, in order to avoid complications arising from the generation of heat in the magnetic coils. The distance between the poles was about 2.5 cm. A Bunsen lamp was placed in the wooden box, and was so regulated as to maintain the iron above it at a very dull cherry-red heat. The German silver wires were connected with the wires of a reflecting galvanometer of six ohms resistance; the connections were separated by paper, bound together and covered with cloth. The lamp was always lighted from four to five hours before any observations were made. It was found that by this time the apparatus had practically reached a condition of thermal equilibrium. At first the current from a battery of ten Grove cells was used; afterwards a battery of twenty-six very large Bunsen cells was used.

After the lamp had been burning for four hours, there was always a permanent deflection of the galvanometer of about 12 cm. When the current was now passed through the magnets, this deflection was immediately changed permanently. The change was found to be due to the direct action of the magnet upon the galvanometer needle, though the distance between the two pieces of apparatus was about 10 meters. This deflection amounted to 2.8 cm. when the stronger current was used. Thirty minutes after the magnet was made, the galvanometer

spot was always found to have changed by about 3 cm. The direction of the change was such as to show that the junction on the magnetized arm was becoming warmer. It was at first thought that this confirmed Maggi's results.

The apparatus was next arranged with one arm of the iron parallel to the axis of the magnet. The arm was passed through the hollow core of an electro-magnet somewhat stronger than the preceding. The same battery was used. The details of the experiment were exactly the same as when the bar was perpendicular to the lines of force. The results of several observations here also showed that the junction on the magnetized arm became hotter under magnetization.

We had previously assumed that the heat developed in the magnetic coil would be too slight to affect the iron bar. This assumption was now proved to be incorrect, by placing the unheated bar, arranged exactly as in the preceding experiments, in the magnetic field. When the magnet was made the galvanometer needle began slowly to move, always in the direction showing a heating of the junction on the magnetized arm. This deflection was slightly larger, after the same space of time, than the deflections observed in the previous experiments, and consequently rendered the results of these experiments useless.

In order to avoid complications arising from the heat generated by the electric current, the following arrangement was adopted. About 17 cm. from one end, the iron bar was bent upon itself. At the end of the bent part, and at the point of the bar opposite this end, were soldered two German silver wires. These two thermo-electric junctions were about 0.4 cm. apart, and were separated from each other by densely packed asbestos. The arm was placed in a glass tube, arranged as before. The bar was heated about 19 cm. from the thermo-electric junctions. By this arrangement the heating of the magnetic coils had an equal effect upon the two junctions, while any change, due to altered conductivity, of the flow of heat along the bar would affect the relative temperatures of the junctions. When the German silver wires were connected as before with the galvanometer, and the unheated bar was placed either parallel or perpendicular to the axis of the magnet, there was, after forty-five minutes observation, absolutely no deflection in the galvanometer. This showed that the arrangement obviated all difficulties arising from heating the coil; and, moreover, that the magnetic field did not perceptibly alter the thermo-electric relation of iron and German silver. When the bar was placed perpendicular to the axis of the magnet,

thin plates of soft iron, running the length of the glass tube, were placed upon the magnetic poles, thus lengthening the field through which the bar passed. The bar was next heated as before. After several hours, the galvanometer generally showed a permanent deflection of 35–40 cm., in a direction indicating that the junction at the end of the bar was the cooler. Several observations were made, both when the bar was parallel and perpendicular to the axis of the magnet. The current was passed for about one hour, and in every case there was absolutely no change of the deflection beyond the immediate change due to the direct action of the magnet.

The result of these experiments seems conclusively to show that longitudinal and transverse magnetism — at least of the strength used — have no influence upon thermal conductivity of soft iron. It was, however, decided to try a thinner piece of iron than the preceding. A strip of ordinary tinned iron was therefore cut about 1.3 cm. wide, and was bent over and arranged exactly as before. The whole tube was packed with asbestos and cotton to avoid any motion of the strip when the magnet was made. The distance of the flame from the two thermo-electric junctions was 10 cm. A heating of ninety minutes was found to be sufficient in this case for the strip to reach a permanent condition of temperature. The deflection showing the difference of temperature between the junctions was about 13 cm. When the magnet was made, there was no change of the deflection after thirty-five minutes' observation.

The strength of the magnetic field when the bar was placed perpendicular to the lines of force was measured after the preceding experiments were made, and was found to be 10,420 times the horizontal intensity of the earth's magnetism at Cambridge. In the C. G. S. system this would be about 1,760.

Aside from the experiments of Maggi, those of Thomson upon electrical conductivity are the only experiments that seem to be directly opposed to the conclusion that must be drawn from our observations. Magnetism undoubtedly changes several physical properties of iron, but though this renders it probable, *a priori*, that the thermal conductivity might be changed, yet it does not necessitate such a change. The thermo-electric relation of iron is changed by magnetization, but the thermo-electric relation appears to be unconnected with thermal conductivity.